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Maunder Missing Link Implies Solar Forcing Cannot be Ignored

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Abstract

Our approach honors the Maunder Minimum and the Modern Maximum, the two bookends, and also honors the large temperature increase of 0.75°C between 1700 and 1950. This temperature increase is attributed to solar forcing, since greenhouse gas (GHG) concentrations are very small or non-existent in this interval.

If the total solar irradiance, TSI, data of one model used by IPCC AR6 is scaled to match both temperature bookends, the hills and valleys in between show significant correlation with Earth's temperature data. While not perfect, the tracking reinforces that solar influence is dominant in this period. This means that solar can still have a significant effect in years beyond 1950 if an upscaled effective TSI is included in the climate model. For example, if sunspot numbers stay constant until 2050, an increase in Earth temperature will reflect GHG forcing. But if sunspot numbers and effective TSI fall, GHG effects will be larger than that measured by Earth temperature rise. However, if sunspot numbers and effective TSI rise, GHG effects will be smaller than measured by Earth temperature rise.

Galactic cosmic rays (GCR) are modulated by the sun's variability, and radionuclides in ice cores have extrapolated solar modulation back 10,000 years. The data indicate that the sun has modulated several glacier retreats on Earth over the past 2,000 years, and confirmed solar forcing of Earth's climate. The search continues for a mechanism that magnifies the TSI effect. An unprecedented heating of Jupiter's atmosphere by solar wind events may offer clues to understand heating of the Earth by solar control.

Keywords: Missing link in climate modeling; Maunder Minimum; DOE Report on greenhouse gases; solar forcing; total solar irradiance; glacier retreats; galactic cosmic rays.

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1. The Maunder Minimum And Correlations With Earth Temperature

A recent Department of Energy Report, Climate Working Group (2025), has pointed out uncertainties in the science of global warming and climate change. One item of the report said: "Moreover, solar activity's contribution to the late 20th century warming might be underestimated [Section 8.3.1]." The DOE authors say that the total solar irradiance, TSI, or its effects, have been suppressed in climate modeling of Earth's temperature rise, by comparison with GHG.

This has been a controversial issue for years. Connolly et al. (2021) made a serious attempt to compare different climate models and their predictions. They found a wide spread of interpretations, but concluded that some previous studies, including IPCC reports, had prematurely concluded no role for the sun in recent decades.

If there's one single data point that says the sun is involved in Earth's temperature over decades, it's the Maunder Minimum. During the Maunder Minimum, about 1700, the Earth was in a deep freeze. Famous scenes were painted of people skating on the River Thames, for example. The

surprise is that there were virtually no sunspots recorded for several decades at this time—the sun’s activity was extremely low. Sunspots are a sign of the sun’s magnetic activity. Fewer sunspots mean less activity, and lower radiation from the sun, called TSI (total solar irradiance). Hence lower temperature at Earth. In climate topics it’s called solar forcing of Earth’s temperature and global warming.

Another correlation is found in the history of glacier retreats. It’s well known that most of the Earth’s glaciers have been shrinking for over 100 years, as a result of global warming. The history of the Aletsch glacier, the largest glacier in the Alps, has been reconstructed from carbon dating of trees killed by an advancing glacier (Beer and McCracken, 2009). Major glacier retreats (by 3 km) have been compiled over the last 3,500 years. Three of these began at 700, 1400 and 1900 years, and the retreats all corresponded to periods of increasing solar activity, and therefore a warming Earth. Each one is a definitive example of solar forcing of Earth’s climate at a time when GHG concentrations were stable.

Solar activity in this example was described by a solar modulation function, which starts from measurement of a radionuclide ^{10}Be in ice cores. The ^{10}Be is found in ice cores after galactic cosmic rays (GCR) collide with molecules in the Earth’s atmosphere. These GCR come into the Earth’s atmosphere from sources in the galaxy such as supernovae. The ^{10}Be concentration is modulated by the Earth’s magnetic field, and by the extended magnetic field of the sun, called the interplanetary magnetic field or IMF, which itself is modulated by the sun’s activity. There are three steps in defining solar modulation. In step 1, measure ^{10}Be found in ice cores. The second step is to remove the effects of the Earth’s magnetic field from the ^{10}Be measurements, leaving the effect of the IMF. Third, use the IMF to quantify the effect of the sun on the energy spectrum of the GCR. The full analysis gives the solar modulation function that can be traced back 10,000 years (Beer and McCracken, 2009). The record reveals sharp dips that correspond to the Maunder Minimum, as well as the two previous solar minima: Spoerer and Wolf. Many other dips in the data testify to solar forcing on Earth’s temperature that controls glacier retreats.

The authors concluded in 2009, “The climate has always changed and will continue to do so in the future. As a consequence, the predictions of the impact caused by anthropogenic activities on future climate change must allow for the natural [solar] variability.... Even though the increase in greenhouse gases is going to be the dominant factor in climate forcing during the coming decades, natural forcing will continue to play a role.”

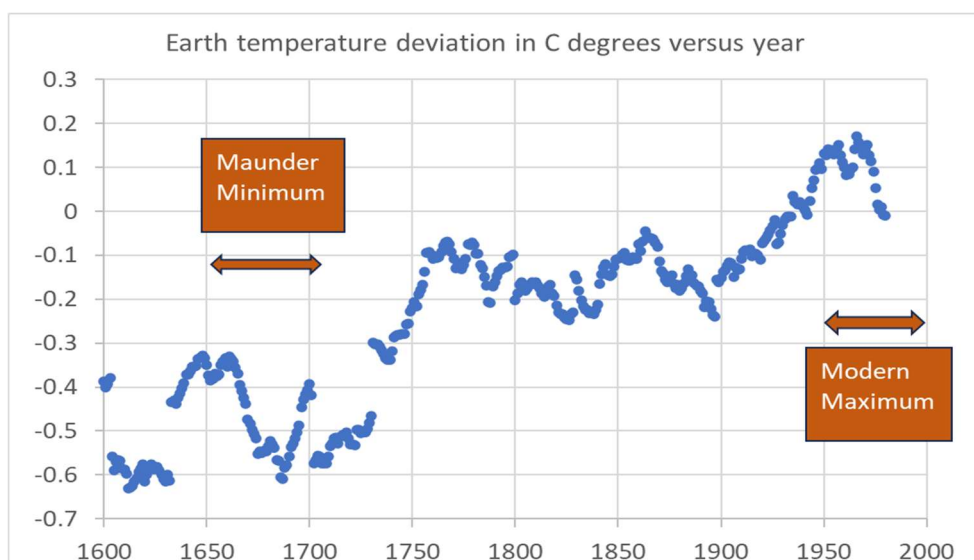


Figure 1. Global warming profile 1600 - 1980. Blue dots are averages of temperature anomalies from Loehle and McCulloch (2008) and are a running mean of 29 years. The temperature rises by 0.75°C between 1700 and 1950. Approved to publish.

2. Earth Temperature And Proxy By Loehle

A plot of Earth's temperature anomaly, published by Loehle (2007), was obtained by averaging 18 separate temperature series over 2,000 years. The series were mostly based on lake sediments and ice cores. By choice, these 18 series have essentially no tree-ring data, which can be affected by precipitation as well as temperature, and are therefore deemed less reliable. The data retained temperature structure, such as the Little Ice Age and the Medieval Warming Period. This medieval period does not appear in the famous hockey-stick profile that was previously used to justify global warming by man-made GHG emissions. In 2008, some minor corrections were made by Loehle and McCulloch (2008) to the data and the corrected plot is shown by Figure 1. This temperature profile will form the basis of correlations that we search for with various TSI proxies.

Other Earth temperature profiles exist. As expected, the Maunder Minimum was conspicuous just before 1700 by thermometers in Central England. A novel reconstruction of Earth temperature, by Mazzarella and Scafetta (2018) was based on the integrated North Atlantic Oscillation (INAO) to estimate global sea surface temperature change. After 1850 this matches sea surface temperature (SST) measurements rather well. Further, it shows the Maunder Minimum between 1700 and 1775.

To keep our analysis simple, we focus on just one reliable temperature profile, because there are many different Earth temperature profiles that have been published.

3. Reconstructions of TSI

Solar irradiance is the amount of power that falls on the surface of the Earth, measured in watts per square meter (W/m^2). The solar modulation function discussed above is one kind of TSI reconstruction, based on the access of GCR to the Earth. The original and simplest proxy for TSI is just the sunspot number, which does roughly trend with earth's temperature. But this has been refined, and a common way to reconstruct TSI is by measuring bright, hot areas of faculae and dark, cool areas of sunspots on the surface of the sun, and using the balance of these to adjust an average solar irradiance. Many such TSI proxies have been published (Connolly et al., 2021).

Note: the sunspot counts go through an average 11-year cycle from minimum to maximum then back to minimum again. But this is not of concern here. What is of concern is the trend in the average yearly values.

One bookend for TSI is the Maunder Minimum between 1660 and 1700 when there were virtually no sunspots. This bookend should be a cornerstone when seeking a correlation between TSI and Earth's temperature. But there exists a second bookend: the Modern Maximum, when around the years 1950-1970 sunspot counts reached a maximum. From 1700 to 1950, over a period of 250 years, Earth's temperature has increased by 0.75°C , which is a lot (Figure 1). Our goal is to match this temperature profile by an effective TSI reconstruction, over a period when man-made GHG were non-existent (up to 1850) or at relatively low concentrations (1850-1950).

The GHG history is shown by Figure 2. Global GHG emissions grow slowly from 1850 to 1950 then rise much faster to 2017. The GHG emissions at 1950 are only about a seventh, or 14%, of their peak in the figure, which supports that GHG forcing is a minor component before 1950. Further, the time period of 1850-1950 reveals Earth temperature decreasing, then increasing, and is not consistent with increasing GHG in Figure 2.

To clarify the GHG emissions: Humans add $\sim 35\text{--}40$ gigatons of CO_2 per year. While that accounts for only $\sim 4\text{--}5\%$ of the total yearly gross output passing through the atmosphere, it acts as a one-way addition, because the rest of GHG released by natural processes (95-96%) is absorbed naturally.

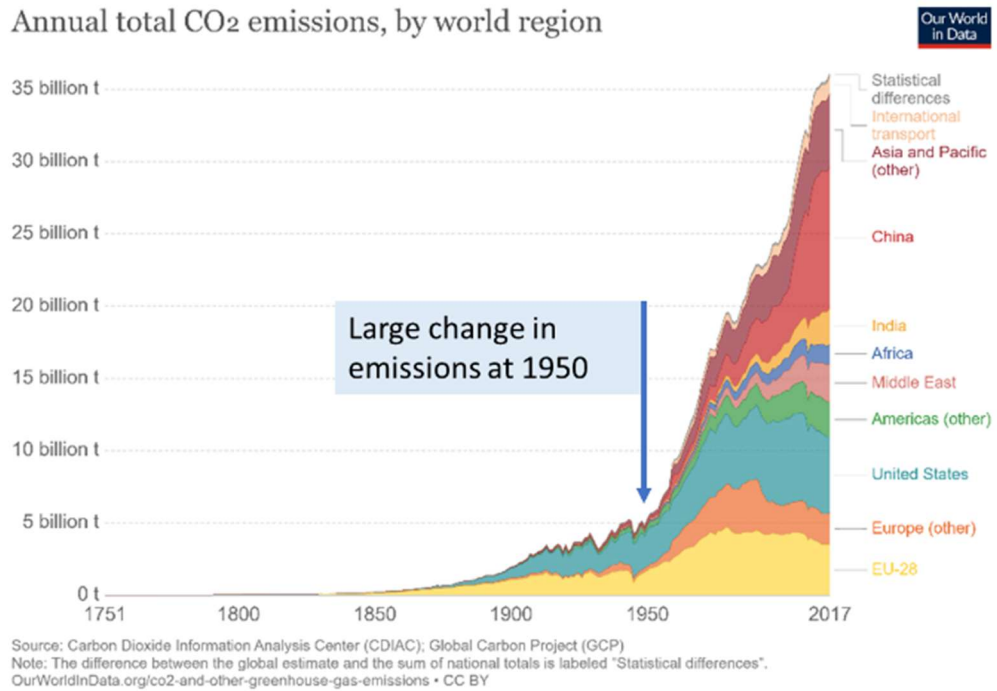


Fig. 2. Global GHG emissions up to 2017. 1950 is a tipping point. Source: Ritchie, Rosado, and Roser 2023. Approved to publish.

TSI reconstructions have been derived from sunspot numbers in different studies since 1995. A recent study by Coddington et al. (2025/2023) was based on normalizing sunspot data to the latest model from NOAA which also reproduces variations in space-based observations since 1978. This was one of two models recommended for use by IPCC AR6 by Mathes et al. (2017). The model result is reproduced in Figure 3.

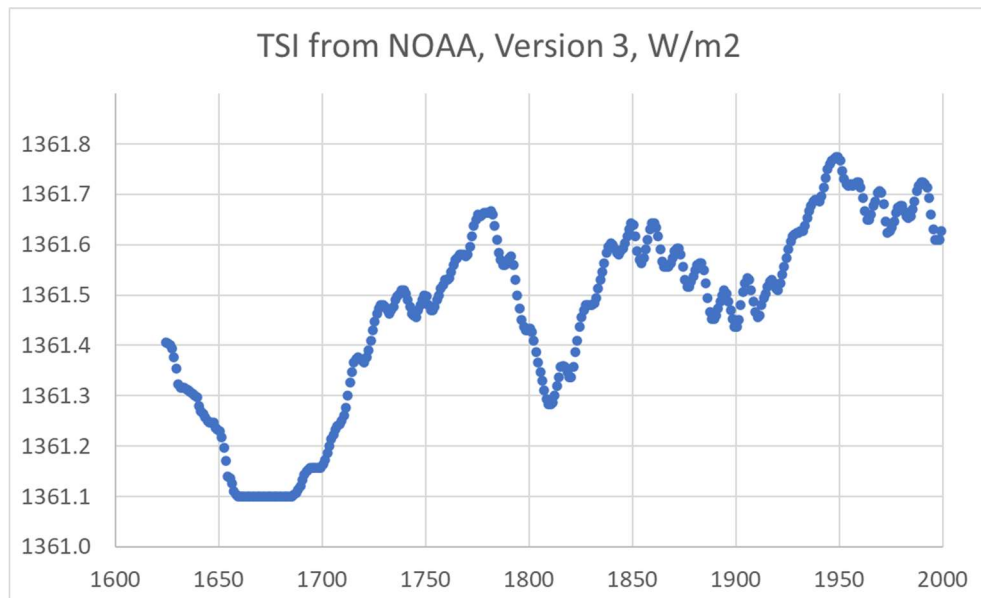


Fig. 3. TSI reconstruction by Coddington et al. (2024). Dots are average yearly values.

The latest Coddington model discusses recent advances in modeling solar irradiance variability, focusing on new NOAA/NCEI data records and model improvements. Version 3 improves modeling accuracy, stability, and spectral coverage based on advanced observations from TSIS-1

and other missions. The bolometric faculae and bolometric sunspot records are the conversion of proxy indices into their respective modulations of a composite total solar irradiance record. Note: the Connolly et al. (2021) include a Coddington model in their discussion. This is an earlier version of the (2025/2023) model.

When comparing Figures 1 and 3, it can be seen that this reconstructed TSI and Earth temperature have similar features. This is emphasized by Figure 4 where the scales have been adjusted to match. When both TSI and temperature have the same two bookends of Figure 1, the hills and valleys in between reveal significant correlation. The tracking between TSI and Earth temperature isn't perfect, but it reinforces substantial solar influence. This is reinforced by the fact that individual temperature series included temperatures determined from ^{18}O isotope, pollens, sea surface temperatures, and other methods. All of these methods are separate and distinct from TSI measurements based on sunspots, and other photosphere displays. Solar forcing must be the dominant mechanism for global warming of 0.75°C from 1700 – 1950.

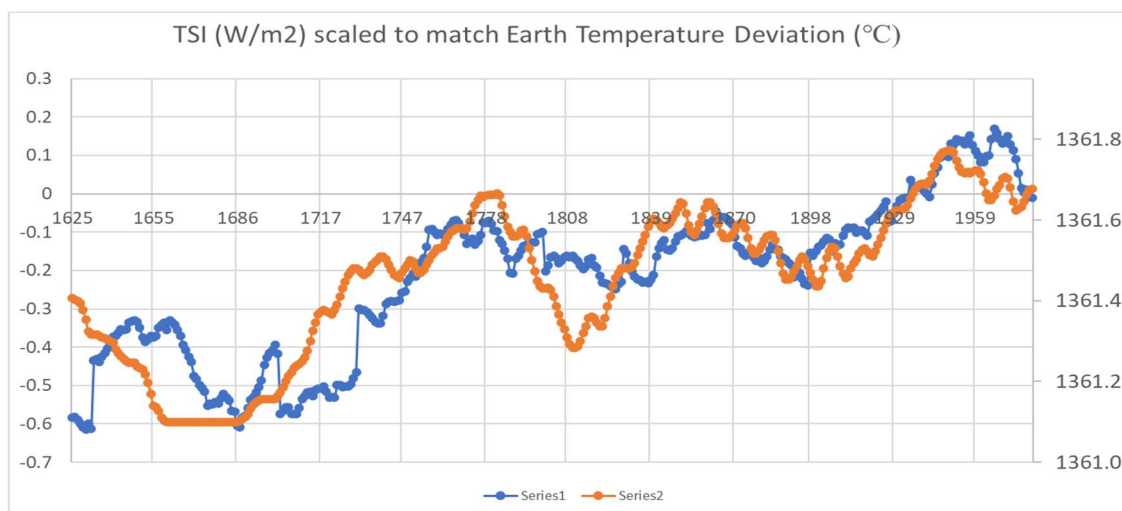


Fig. 4. Orange dots and right scale, TSI from Coddington et al. (2024) is scaled to best match Earth temperature of Figure 1 (Blue dots and left scale).

4. Defining An Effective TSI

A second observation from Figure 4 is that the TSI numbers vary from 1361.1 to 1361.8 W/m^2 but this spread of 0.7 W/m^2 in a climate model will not cause Earth temperature to rise in Figure 1 from -0.6 to $+0.15^\circ\text{C}$, an uplift of 0.75°C . The DOE Report summarizes the discrepancy: IPCC AR6 (2021) says that natural drivers such as solar forcing, since 1850, have only changed Earth temperature in a range of -0.1°C to $+0.1^\circ\text{C}$, which is a minor amount when trying to interpret Figure 1. Although acknowledging reports that a spread of values for TSI of $0.7 - 2.7 \text{ W/m}^2$ have been deduced since the Maunder minimum, AR6 settled on the low end of the range for their official climate modeling studies—what is called low variability TSI (Mathes et al., 2017).

There do exist spacecraft measurements of TSI since 1978, so that should have resolved this problem of low or high variability in TSI proxies. Although there are inconsistencies in the data from rival spacecraft, NOAA have normalized their model behind Figure 3 to space-based observations to some degree, making it a low variability TSI model. The result from IPCC AR6, which uses a model close to the NOAA model, indicates virtually no solar forcing in climate predictions after 1750. Critically, the Maunder minimum around 1700 wasn't included in the analysis, despite Earth's temperature rising by 0.5°C between 1700 and 1750, which has to be solar forcing because there were no man-made GHG present. This is a serious omission.

The situation has been addressed in a review by Connolly et al. (2021). The paper tried to match

Earth's temperature by individual TSI proxy models—eight low variability and eight high variability models. Table 1 focuses on temperature from rural-only or ocean sources, as these are deemed the most reliable. When the models are matched to temperatures in the approximate time interval 1850 – 2000, low variability models give a solar forcing contribution less than 36%. But four out of five high variability models give 100% solar forcing. These trends are as expected.

The lower variability solar models have a smaller TSI spread of 1-1.5 W/m² over the period 1700 – 2000 because they are normalized to satellite data. The higher variability TSI models are not so confined by satellite data, and have a larger TSI spread of 3-4 W/m². But these high variability models can match the entire temperature range of 0.75°C from 1700 to 2000, including the temperature jump of about 0.5°C from 1700 to 1760 (Figure 1). Inclusion of the Maunder Minimum pushes the modeling to use larger values of TSI, which we refer to as a magnified or effective TSI. Note that the 100% solar forcing in Table 1 is an overestimate, due to linear least-squares fits used to approximate the observed trends, which may not be linear, in observed or modeled temperature.

Table 1. Matches of Earth temperature adapted from Connolly et al. (2021). The top row are the spreads of TSI for low and high variability TSI proxies. The third row contains the match results over the reduced time period 1850-2000.

Low variability models			High variability models		
Fig. 2	1700-2000	1-1.5 W/m ²	Fig. 3	1700-2000	3-4 W/m ²
Fig. 15	1850-2000 Rural-only or ocean	Most models are 22-36% solar forcing	Fig. 16	1850-2000 Rural-only or ocean	4/5 models are 100% solar forcing
Conclusions:	Satellite data pushes TSI to lower W/m ²		Maunder Minimum temperature jump of 0.5°C from 1700-1770 pushes to higher effective TSI.		

Another study of TSI scaling has been done by Ammann (2007) who shows how sensitive the Earth's temperature is to solar forcing. The approach is to model three different TSI scalings in a sophisticated climate model to try to match Earth's temperature. The medium scaling applied to TSI predicts Earth's temperature of Figure 1 quite well. It predicts a range of -0.7°C to +0.2°C from Maunder Minimum to the Modern Maximum. For this medium scaling, GHG forcing clicks in at 1920, but remains at a low level until 1950 after which it becomes dominant.

An alternative approach has been made by Scafetta et al. (2023), with a goal to match Earth temperature by a model with magnified TSI, another word for effective TSI. The paper claims that the IPCC climate models (Matthes et al., 2017) focus on a low variability TSI and underestimate the sun's influence. They conclude TSI has to be magnified by a factor of 5 because their modeling shows other mechanisms contribute 80% of the sun's influence on Earth temperature. For comparison, Table 1 suggests a factor of 3-4. The solar modulation of GCR which affects cloud formation is offered as one such mechanism.

There is one caveat: Similar to Connolly et al. (2021), the paper seeks to match a restricted period of Earth temperature from 1850 – 2020, a period when GHG do have a significant and increasing effect. But once again, the Maunder Minimum is missing, along with the dramatic temperature increase by 0.5°C between 1700 and 1760—an indisputable case of solar modulation. Note that volcanic forcings were also included in the Scafetta modeling, because they are prominent in the period 1850 - 2020.

Some of the three grouped proxies of Scafetta matched Earth temperature better than the IPCC matches in the period 1850 – 2020. Further, two of the grouped proxies outperform the third grouped proxy, and the former are weighted more on the high variability side. Last, the results imply that GHG influence on Earth temperature by IPCC is overestimated in this period, and

that solar modulation could be almost comparable with the impact of man-made GHG. Documentation in a new book by Scafetta (2026) finds that 50% of the warming in the period 1850 – 2020 is attributable to solar (or stronomical) forcing, while 30% is due to GHG.

It's worth noting that the Scafetta analysis in the period 1850 – 2020 argues for a relatively significant GHG forcing of 30%, while in a complementary period of 1700 – 1950 we find there is very little GHG forcing (see Figure 4). These conclusions directly challenge the modeling of IPCC AR6.

In summary, the two bookends in Figure 1 represent a global warming of 0.75°C between 1700 and 1970, and the major cause is solar forcing. It appears that IPCC AR6 focuses on temperature after 1750 using a low-variability TSI proxy, like Coddington et al. (2024), but underweighted the Maunder Minimum around 1700. The large temperature rise of 0.5°C between 1700 and 1760 cannot be due to GHG forcing, but can be explained by high variability TSI proxies. The exclusion of such a large Earth temperature change, which can only be due to solar forcing, leaves less confidence in the AR6 predictions of climate change going forward.

5. Mechanisms To Magnify Solar Forcing

To include the missing Maunder Minimum requires a magnified TSI, as shown above.

As summarized by the DOE Report, “Scientists have searched... but first a calculation of TSI at the Earth has to be found that will cause enough forcing of temperature. Two camps have emerged: one that says TSI is almost negligible in its effect on Earth’s temperature, and the other says the opposite.” Our argument of the previous section was that TSI is critical, because between 1700 and 1950 Earth’s temperature rose by 0.75°C (Figure 1) when GHG emissions were non-existent, or very low in the years 1900-1950.

5.1 Glacier Retreats

A broader picture looks at how the sun’s activity affects other variables that impact Earth. One is the solar modulation of glacier retreats, described above. Glacier retreats and subsequent advances have been known since about 1800, before any industrial CO₂ appeared. Solar modulation is a TSI proxy that has been back-calculated 10,000 years and shown to correlate with glacier retreats in the last 2,000 years (Beer and McCracken, 2009). This is direct evidence of solar forcing on Earth temperature.

5.2 Galactic Cosmic Rays

A second mechanism is galactic cosmic rays (GCR) which stream into interplanetary space from outside the heliosphere. GCR are clearly modulated by the sun’s activity, meaning sunspots (Beer and McCracken, 2009). GCR enter the atmosphere of Earth, collide and ionize air molecules, and form radionuclides such as ¹⁰Be that end up in ice cores.

Figure 5 shows a fairly strong matching of the hills and valleys when Earth temperature is compared to GCR between the bookends of Maunder Minimum and Modern Maximum. It’s likely that the vertical swings in temperature are less than the swings in GCR because temperature data is found by averaging 18 different temperature series with a running average of 29 years. Note again that individual temperature series included temperatures determined from ¹⁸O isotope, pollens, sea surface temperatures, and other methods. All of these methods are separate and distinct from GCR measurements determined from ¹⁰Be radionuclides measured in ice cores. This is credible support that GCR are a driver of Earth’s temperature.

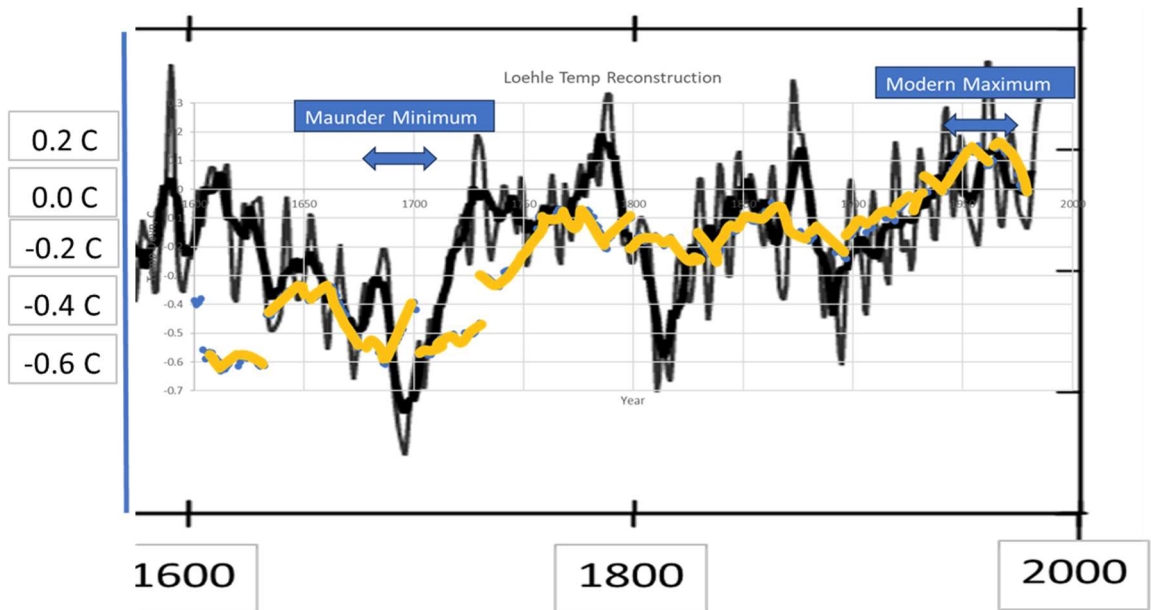


Fig. 5. Earth temperature plot from Figure 1 (yellow) superimposed on GCR calculated from ^{10}Be in ice cores by McCracken and Beer (2015). Darker black line is a running average.

But what is the mechanism? Those molecules ionized by GCR can cause clouds to nucleate, and alter the albedo, which reflects and changes the incoming radiation from the sun. This was first introduced in a seminal paper by Svensmark and Friis-Christensen (1997). When the interplanetary magnetic field (IMF) increases because sunspots increase, GCRs recorded at Earth decrease because more of them are reflected backwards by a higher interplanetary magnetic field. Fewer GCRs penetrating to Earth's atmosphere would mean fewer clouds to reflect heat and thus more global warming.

This hypothesis has become a prolonged debate, with many articles on each side of the issue. An interesting item in the latter stages of the debate is a correlation between Forbush decreases (FD) and cloud cover. FDs are sudden drops in GCR measurements by neutron monitors, followed by a more gradual recovery. They are occasional events, typically a few each year, following a CME. Svensmark et al. (2016) concluded that "there is a real influence of FDs on clouds probably through ions". This means GCR that cause Forbush decreases after CMEs also affect Earth temperature via changes in cloud cover.

The cloud cover hypothesis was explored by Ollila (2017). His theoretical calculation of Earth's temperature increase from 1700 using low TSI values (such as Coddington et al., 2024) would be only 0.12°C . To get around this, Ollila proposed the temperature increase was magnified by a decrease in GCRs reaching the atmosphere. He argued that a temperature rise of 0.50°C could be caused by a direct TSI increase of 0.12°C added to a cloudiness decrease of only 2.7% which would boost Earth's temperature by 0.38°C . The effective TSI would be magnified by a factor of $0.5 / 0.12 = 4.2$. This calculation was based on a TSI proxy by Lean (2015). However, this TSI proxy has been updated by Coddington et al. (2024), and the old TSI spread of 2.75 W/m^2 has been reduced to 0.7 W/m^2 in Figure 3. This could mean the effective TSI would have to be magnified by more than 4.2 times, and the GCR-induced cloud cover would have to decrease by more than 2.7% to raise Earth temperature enough.

The truth is, the mechanism of the effect of GCRs on Earth temperature is controversial. The review by Connolly et al. (2021) summarizes many publications pro and con. The main topic has been the effect of GCR on cloud cover. GCR do influence cloud formation but cloud cover understanding is limited. Despite the debate, a conclusion of the review is that GCR changes could be a driver of Earth temperature changes. This is supported by the correlation between solar modulation of GCR and warming glacier retreats, which is definitive over a couple of

thousand years. A causative link between GCR and Earth's temperature doesn't seem implausible, but has not been proven.

There is firm evidence that occasional enhanced pulses of ^{10}Be in ice cores are caused by large fluxes of solar cosmic rays that enter Earth's atmosphere (McCracken and Beer, 2015). It would be worth checking to see if these are associated with increases in Earth temperature. If proven, this would support the case that GCR are responsible for changes in Earth temperature, a la Figure 5.

5.3 Interplanetary Magnetic Field

A third possible mechanism is the interplanetary magnetic field (IMF) which comes from the sun and stretches way past the outermost planets. The IMF is carried outwards by the solar wind and bumps into the magnetic field of the Earth, while the solar wind is diverted around it. One extreme of solar influence is when a coronal mass ejection (CME) starts as a large explosion at the sun, then a couple days later collides with Earth, causing aurorae and disrupting radio communications and other technology devices. But this only happens occasionally.

In the absence of spacecraft measurements, the IMF can be reconstructed from GCR measurements, because they are anti-correlated. When solar activity rises, the IMF strengthens, and pushes GCR back. So, an IMF proxy can be obtained from the GCR history over the past 10,000 years, and then normalized to spacecraft measurements of IMF since 1968. When plotted, the IMF looks a lot like Figure 5 here (Beer and McCracken, 2009), and reveals an insightful correlation to Earth temperature. This could mean the IMF is the driver of temperature, and not GCR. It's not hard to imagine the IMF, which completely embraces the Earth's magnetic field and its long tail, might be influencing the temperature of the body wrapped inside it.

5.4 Heating of Jupiter's Atmosphere

A high-pressure, fast moving solar wind burst, presumably a CME, banged into Jupiter in January 2017, compressed its magnetosphere, and generated thermospheric winds similar to LSTIDs at Earth (O'Donoghue et al., 2025). LSTIDs are ionospheric waves that can cause variations in plasma density and temperature, which can affect the integrity of radio wave communications. The hot thermospheric winds, starting from the auroral oval, transferred enormous amounts of energy and heat to the atmosphere of Jupiter, which went from an average of 350°C to 500°C for several hours. The superhot region covered half of the planet in longitude, and several degrees of latitude.

The Keck II telescope, a ground-based instrument in Hawaii, recorded the superhot region on Jupiter. The authors quote the incident as unprecedented, but that solar wind bursts may impact Jupiter 2-3 times each month. The paper demonstrates that the solar wind can have a serious effect, beyond auroral regions, on temperature of the upper atmosphere of Jupiter. Maybe new mechanisms will be found for energy transmission and atmospheric temperature increases in Jupiter, that might also apply to solar forcing of Earth's temperature.

Per a suggestion by one reviewer, a literature search was done on whether this Jupiter effect could happen on Earth. One review summarized it this way: When a CME hits Earth, it triggers a geomagnetic storm that causes widespread heating in the thermosphere of Earth (85 to 600 km above the surface). The heat is spread to lower latitudes via higher-altitude atmospheric winds. But unlike Jupiter, Earth's thermosphere has a built-in cooling mechanism. Heating stimulates nitric oxide (NO) and carbon dioxide (CO₂), which emit infrared radiation back into space, efficiently cooling the thermosphere down to where it was before the storm. The extreme heating is confined to the ultra-thin air of the upper atmosphere; CMEs do not alter the temperature of Earth's lower atmosphere or surface weather.

Apart from the system cooling itself, which seems rather fortuitous, the chain of events from stronger solar activity to more CMEs to more heating of the Earth's thermosphere does seem like

a possible explanation for heating of Earth's surface. Along these lines, a review paper by Gomes et al. (2012) provided an overview of possible relations between strong solar winds and cyclonic motions in the Earth's atmosphere, meaning cyclones, depressions, storms, hurricanes, etc. One example presented is three hurricanes that appeared together with a number tornados 27 days apart (i.e. one solar rotation apart) in August-October 2005, strongly suggesting a solar origin.

6. Conclusions

The analysis here matches Earth's temperature of Loehle (2017) by scaling up or magnifying the low variable TSI of Coddington et al. (2024) and by honoring the Maunder Minimum and Modern Maximum. These two bookends are confirmed by independent data. Between the two bookends, corresponding peaks and valleys support a dominant solar influence in the period 1700 – 1950 which causes a global warming of 0.75°C. The temperature plot is based on 18 separate series of measurements, but essentially does not include tree-ring data. Errors in the original data have been corrected. The temperature plot is a 29-hour running average, and this means small wiggles can be unreliable. Although data swings are damped, overall trends are reliable, and these are the basis for comparisons in this paper.

The tracking between effective TSI and Earth temperature, independent measurements, isn't perfect but it argues for substantial solar influence. This is reinforced by the fact that individual temperature series included temperatures determined from ¹⁸O isotope, pollens, sea surface temperatures, and other methods. All of these methods are separate and distinct from TSI determinations based on sunspots, and other photosphere displays. Solar forcing must be the dominant mechanism for global warming of 0.75°C from 1700 – 1950.

It appears that IPCC AR6 ignores the Maunder Minimum around 1700 in its choice of TSI and in its matching of Earth temperature—and ignores a temperature jump of 0.5°C between 1700 and 1760. AR6 uses a low variable TSI that honors satellite measurements of TSI, and focuses on matching Earth temperature starting at 1750. The exclusion of the Maunder Minimum temperature rise, which can only be due to solar forcing, leaves a serious bias in the AR6 modeling and less confidence in AR6 predictions of climate change going forward.

In seeking an effective TSI that is magnified, we look at how the sun's activity affects other variables that impact Earth. One is the solar modulation of glacier retreats. Solar modulation is a TSI proxy based on galactic cosmic rays that has been back-calculated 10,000 years, and shown to correlate with glacier retreats in the last 2,000 years (Beer and McCracken, 2009). This is direct and critical evidence for solar forcing on Earth temperature before man-made GHG emissions. The tracking of hills and valleys between GCR and Earth temperature profiles in the period 1700 to 1950 is tantalizing support that GCR are a driver of Earth's temperature. This gains credibility because each of the individual temperature series were determined from methods that are separate and distinct from GCR measurements determined from ¹⁰Be radionuclides in ice cores. In all, the well-established solar modulation of galactic cosmic rays and interplanetary magnetic field, both of which are known to affect the electromagnetic field around the Earth, are candidate mechanisms for solar modulation of Earth's temperature, but are not proven as yet.

A high-pressure, fast moving solar wind burst, presumably a CME, has recently been associated with a dramatic, unprecedented heating of Jupiter's atmosphere from 350°C to 500°C. Maybe this will lead to new mechanisms for energy transmission and atmospheric heating in Jupiter, which might apply to solar forcing of Earth's temperature.

In a model with magnified effective TSI, solar forcing is dominant from 1700 to 1950 when Earth temperature increases by about 0.7°C. After this, GHG forcing becomes dominant but solar forcing cannot be neglected. For example, if sunspot numbers stay constant until 2050, an expected increase in Earth temperature would reflect GHG forcing. But if sunspot numbers and

effective TSI fall, GHG effects will be larger than that measured by Earth temperature rise. However, if sunspot numbers and effective TSI rise, GHG effects will be smaller than measured Earth temperature rise. In this case, the oil and gas industry, which is responsible for about 50% of worldwide GHG emissions, would be less culpable in the matter of global warming.

Clearly, future solar changes, whether minor or large, will be important to know how to deal with climate change in the coming decades. For example, Coddington et al. (2024) predicts in the years 2030–2100 that TSI will be about 70% greater than current values (using a basis of zero at the Maunder Minimum). If effective TSI were proportionally greater, this would equate to ~3.3°C of temp rise that would not be caused by GHG.

The DOE Report on GHG is correct—solar forcing is underestimated in IPCC AR6 modeling. An effective magnified TSI proxy needs to be used to honor the Maunder Minimum. But more research is needed to find out what magnifies TSI.

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